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G01S 13/534

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None

(58) Field of Search
UK CL (Edition H) H4D
INT CL^4 G01S

(54) Radar

(57) A radar transmits pulses at frequencies selected, at random, from a progressively decremented number of available frequencies. The corresponding returns are ordered in accordance with a monotonic sequence of the transmitted frequencies and then subjected (24) to a Fast Fourier Transform to derive a plurality of transformation signals representing a distribtion of pairs of scatterers (target and/or clutter) as a function of their differential range. Selected differential range cells are monitored to detect a target.

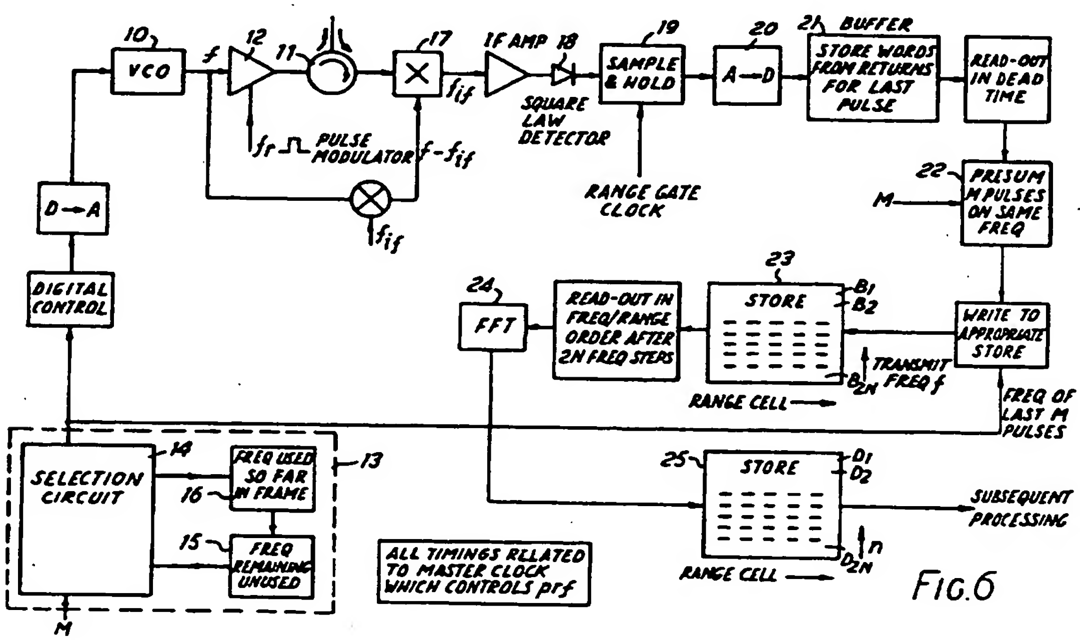

FIG.6

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

The claims were filed later than the filing date within the period prescribed by Rule 25(1) of the Patents Rules 1995

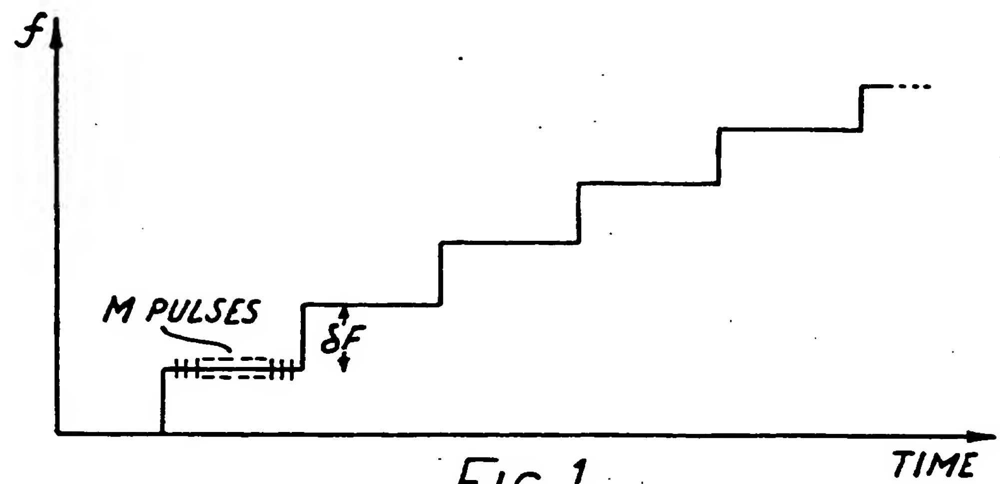


FIG.1

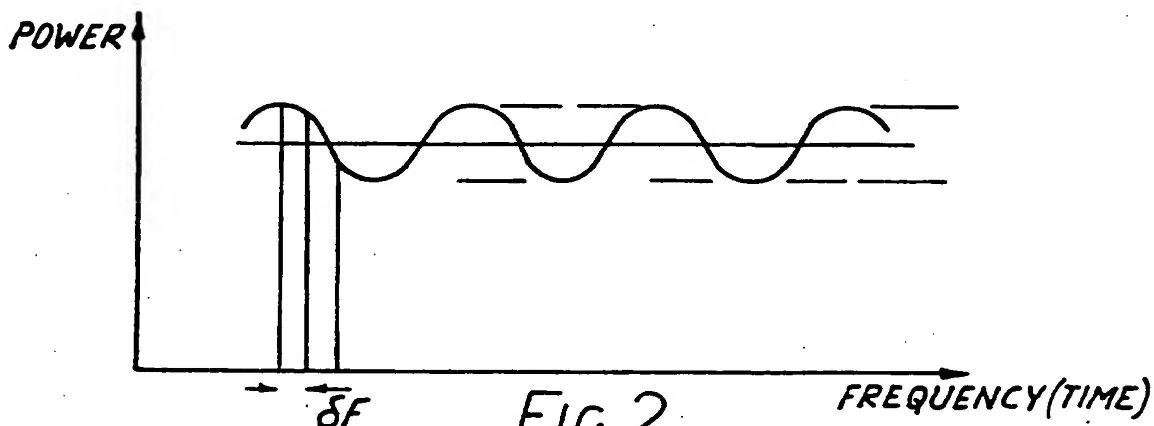


FIG.2

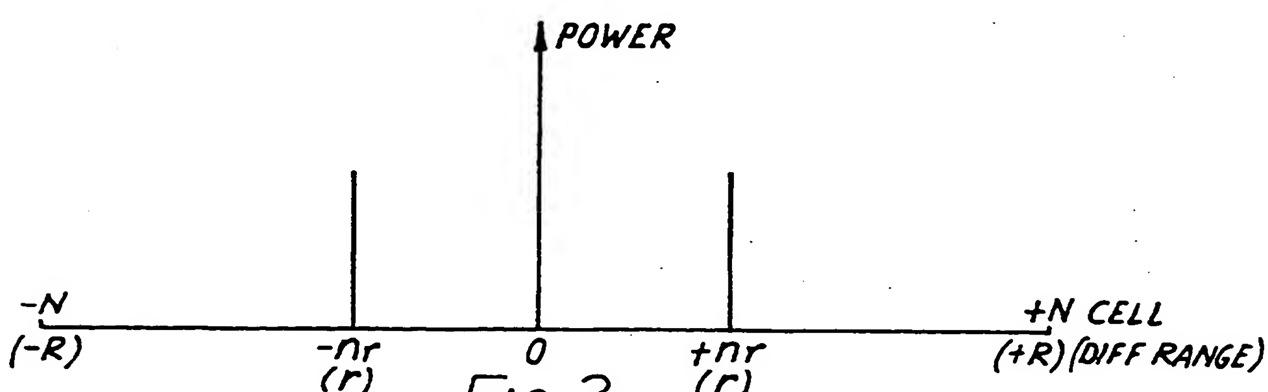


FIG.3

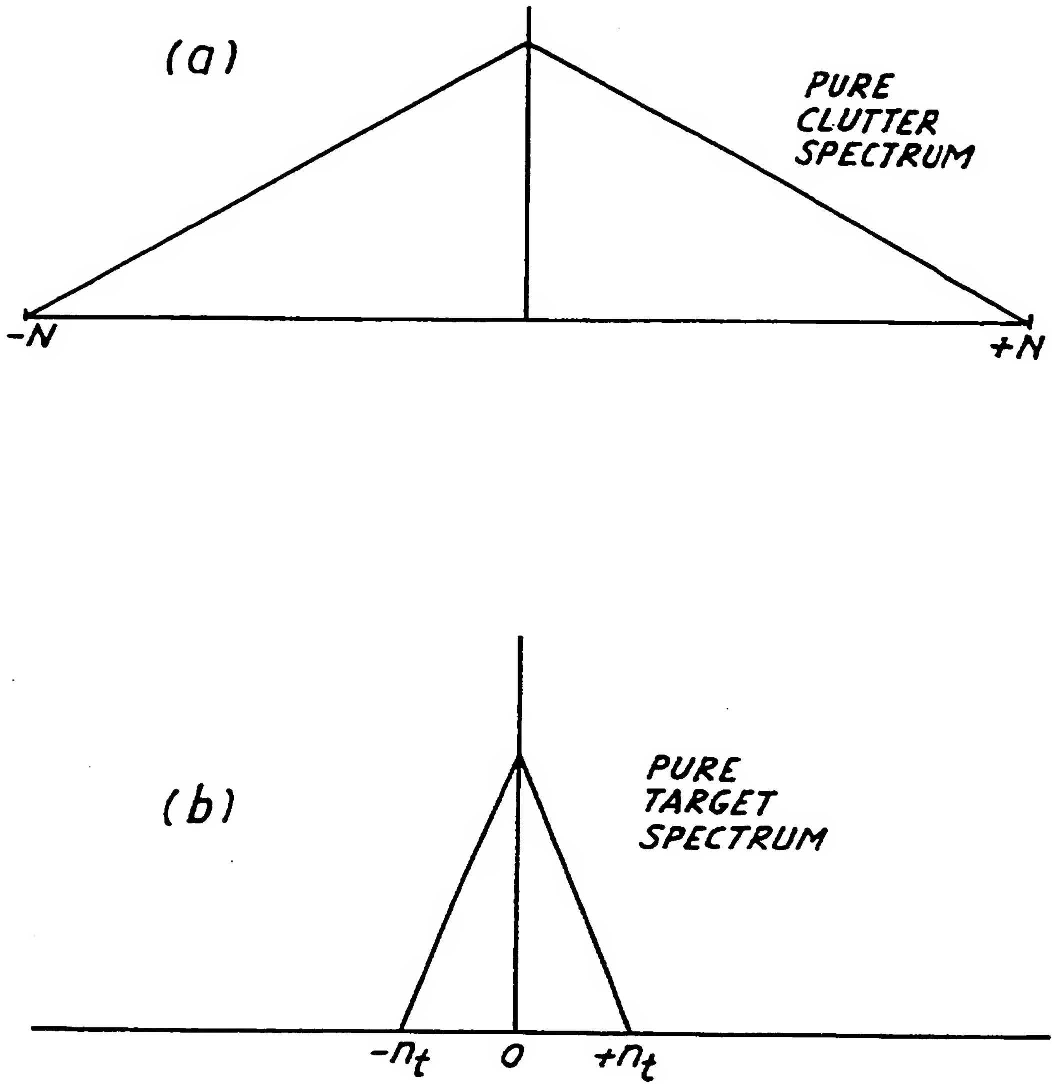


FIG. 4

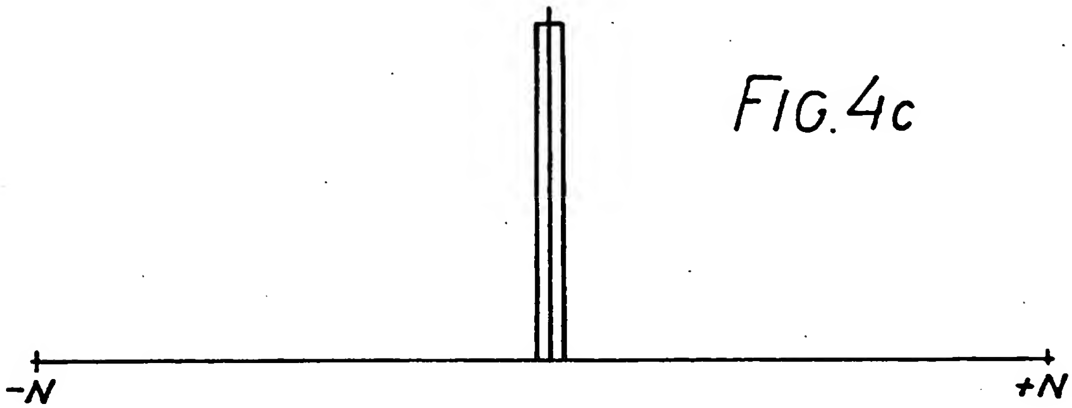
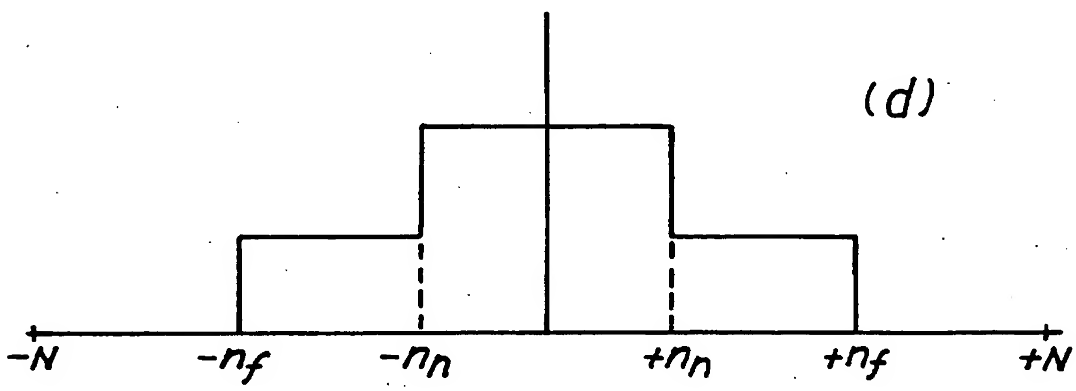


FIG.4c

(d)



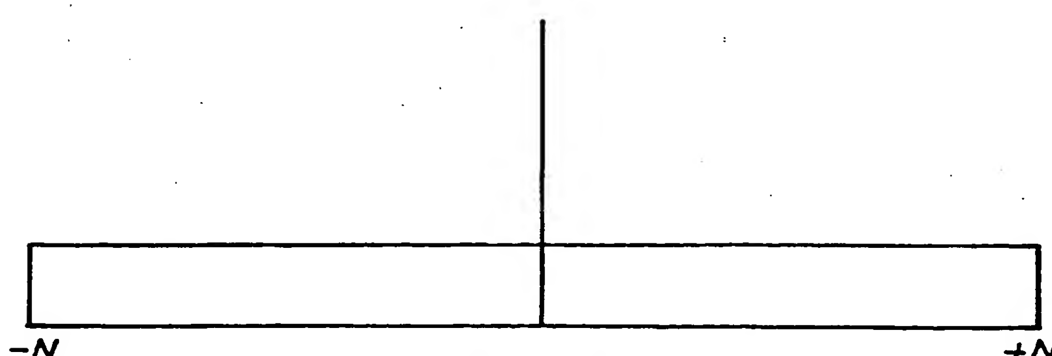


FIG.5

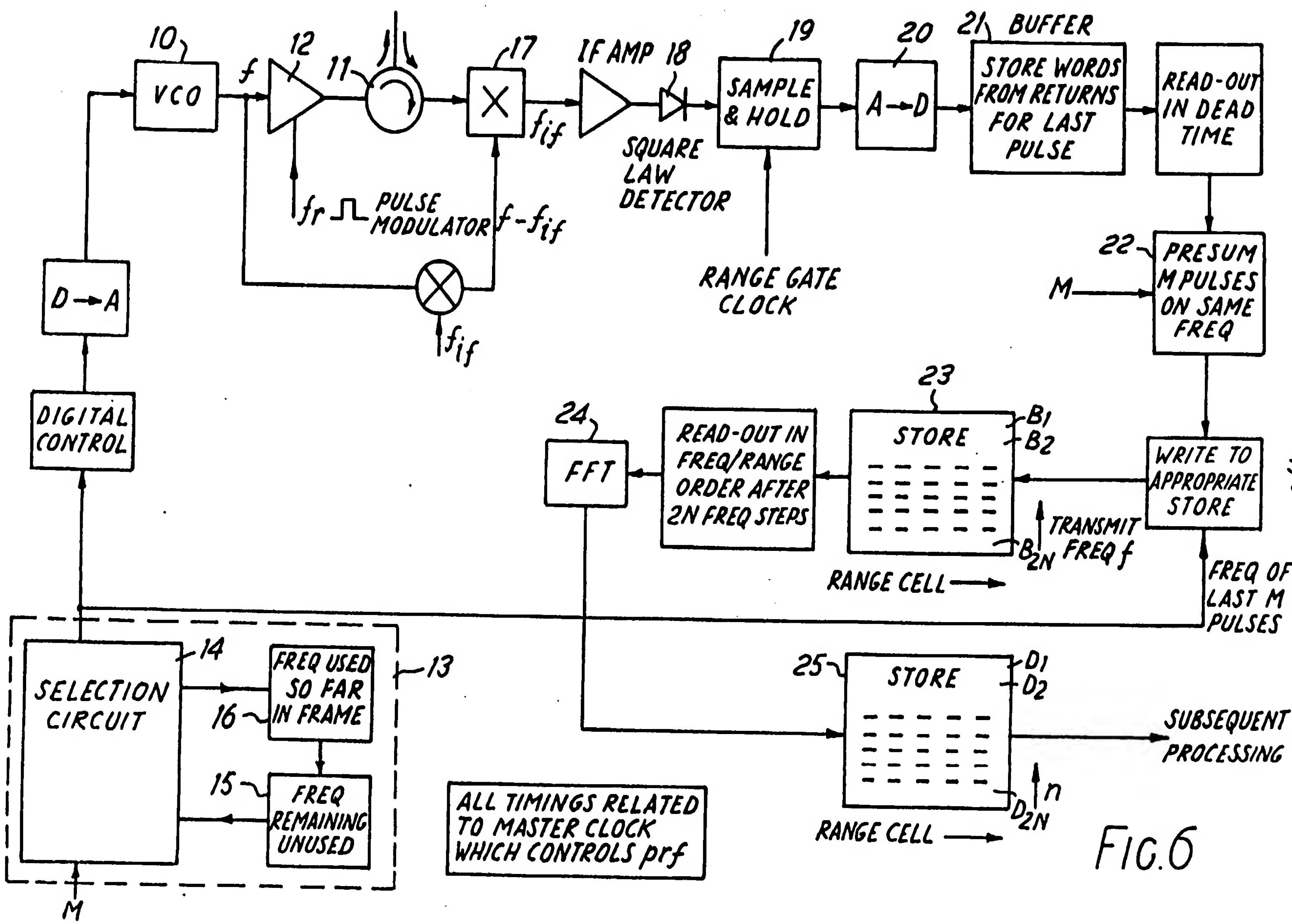

10
VCO
f
12
11
17
fif
IF AMP 18
SQUARE LAW DETECTOR
fr
PULSE MODULATOR
f - fif
fif
19
SAMPLE & HOLD
RANGE GATE CLOCK
20
A→D
21 BUFFER
STORE WORDS FROM RETURNS FOR LAST PULSE
READ-OUT IN DEAD TIME
22
PRESUM M PULSES ON SAME FREQ
M
WRITE TO APPROPRIATE STORE
FREQ OF LAST M PULSES
TRANSMIT FREQ f
23
STORE
B1
B2
B2N
RANGE CELL
READ-OUT IN FREQ/RANGE ORDER AFTER 2N FREQ STEPS
24
FFT
25
STORE
D1
D2
D2N
n
RANGE CELL
SUBSEQUENT PROCESSING
D→A
DIGITAL CONTROL
13
14
SELECTION CIRCUIT
FREQ USED SO FAR IN FRAME
16
15
FREQ REMAINING UNUSED
M
ALL TIMINGS RELATED TO MASTER CLOCK WHICH CONTROLS prf

FIG.6

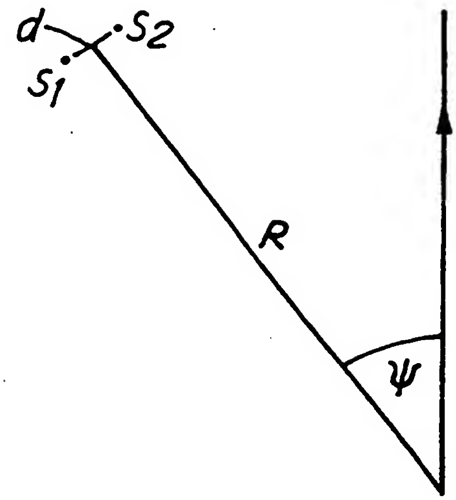


FIG.7

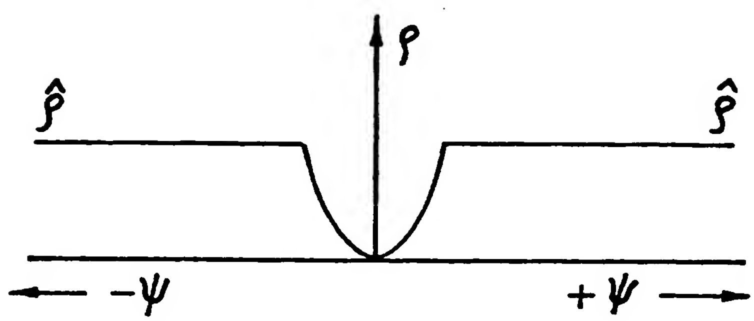


FIG.8

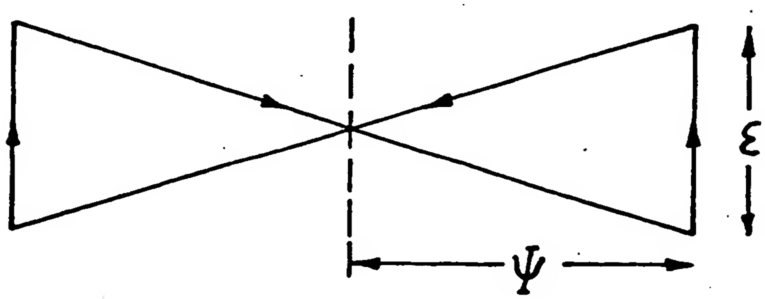


FIG.9(a)

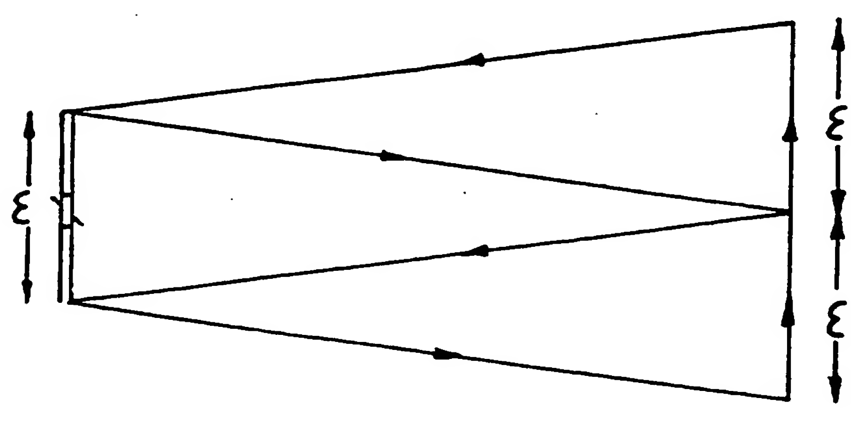


FIG.9(b)

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RADAR

This invention relates to a radar and it relates especially, though not exclusively, to a radar used in a terminally-guided sub-munition (TGSM) operating in search and tracking modes.

There has arisen a need to improve the performance of a non-coherent pulsed radar for the detection and tracking of targets, such as tanks or trucks in a background of clutter.

Accordingly there is provided a radar comprising means for transmitting a succession of pulses at different frequencies and for receiving corresponding returns, transformation means effective to derive from said returns a plurality of transformation signals representing a distribution of pairs of scatterers which comprise the target and clutter, irradiated by the pulses, as a function of differential range, and means to influence transmission of said succession of pulses so as to selectively emphasise the effect of targets in said plurality as compared with the effect of clutter,

successive frequencies being selected, at random, from a progressively decremented number of available frequencies before they are passed to the transformation means.

In order that the invention may be carried readily into effect specific embodiments thereof are now described, by way of example only, by reference to the accompanying drawings of which

Figure 1 shows a step-wise variation of transmission frequency as a function of time,

Figure 2 illustrates a variation with frequency in the power detected at a radar receiver,

Figure 3 shows a mapping of a pair of scatterers in the differential range domain,

Figures 4a, and b, show respectively idealised representations of pure spectra for clutter and target scatterers,

Figure 4c shows the pure spectrum for a point target scatterer,

Figure 4d shows an idealised representation of a hybrid spectrum derived from a point target scatterer and a distributed assembly of clutter scatterers,

Figure 5 shows the hybrid spectrum after "whitening",

Figure 6 shows a radar in block schematic form,

Figure 7 shows a antenna beam scanned in azimuth,

Figure 8 shows how an improvement in signal-to-clutter ratio $\hat{\rho}$ varies as a function of azimuthal scan angle ψ, and

Figures 9a and 9b show alternative scanning patterns,

In one application, it is intended that a radar in accordance with the present invention will be carried by an airborne vehicle - for example a terminally-guided sub-munition (TGSM) operating in search and tracking modes to respectively detect, and home on to, targets such as tanks or trucks deployed on the ground.

The radar is designed to exploit the different spatial dispositions and extensions of scatterers comprising target and

clutter respectively, within the region illuminated by the radar pulse. To this end, the radar exploits an effect which can be understood by considering first, a simplified example in which a non-coherent radar illuminates a pair of scatterers spaced apart from one another, down range by a distance r, hereinafter referred to as differential range. The radar frequency f is swept, in stepwise manner, over a frequency range F, the frequency of 2N successive batches of M pulses being incremented in steps of $\delta f = \frac{F}{2N}$, as illustrated in Figure 1.

As the frequency is swept in this manner, so the relative phases of returns from the two scatterers will change causing an oscillatory variation with frequency in the power of the pulse returns from the scatterers detected at the receiver, as shown in Figure 2. A frequency analysis of returns, for example a Discrete Fourier Transform (DFT) of returns produces a mapping of the pair into 2N cells in the differential range domain. Thus, in the described example a "line" is produced in cells $\pm n_r$ corresponding to the differential range r, as shown in Figure 3, and the $\pm N^{th}$ cells correspond to the maximum resolvable differential range R which is related to the bandwidth B of the radar by the expression

$$R = \frac{c}{2B} \qquad \text{Eq. 1}$$

where c is the speed of light.

In general targets or clutter consist of a distributed assembly of scatterers and produce a distribution of energy in

the differential range domain, hereinafter referred to as a spectrum. The spectrum from clutter, whose scatterers are assumed to be spread uniformly across the whole of the patch illuminated by the radar pulse, will be relatively broad, as shown in Figure 4a, whereas a target (e.g. a tank or truck) being confined to a relatively small region of space will produce a narrower spectrum of the form shown in Figure 4b. It will be appreciated that the output from the DFT will consist of 2N samples although for convenience the envelope of the spectra are drawn as being continuous. These spectra, which are referred to hereinafter as pure spectra, are produced by returns from many pairs of scatterers each pair consisting respectively of two target scatterers or two clutter scatterers. It is also possible, however, to obtain a hybrid spectrum due to pairs, each consisting of one target scatterer and one clutter scatterer. The individual clutter in these various spectra will consist of returns from multiple pairs of scatterers having a spread of differential ranges, this spread being approximately $\frac{c}{2F}$, the differential range resolution of the system.

A hybrid spectrum may be understood by considering first the effect of returns from a stationary point target scatterer interferring with returns from an assembly of clutter scatterers, distributed uniformly across the range cell. In these circumstances the pure spectrum, due to the target scatterer, has the form shown in Figure 4c whereas the pure

spectrum due to the clutter scatterer has the form shown in Figure 4a.

If the range differential between the target scatterer and one (the near) edge of the range cell corresponds to the n_n^{th} cell in the hybrid spectrum and the range differential between the target scatterer and the other (the far) edge of the range cell corresponds to the n_f^{th} cell in the hybrid spectrum, so that $n_n \leqslant n_f$ then for a point target scatterer the hybrid spectrum will be of the form shown in Figure 4d. In general, the hybrid spectrum for an extended target will be more complex.

In practice, an observed spectrum will generally comprise a mixture of both pure and hybrid spectra and an individual line may include contributions from different pair combinations i.e. target/target; clutter/clutter; clutter/target.

It will be appreciated that the spectra derived in this way represent, in effect, the autocorrelation function of the distribution in range of the individual scatterers illuminated by the radar.

The two spectral lines shown in Figure 3 are shown as being identical for positive and negative values of differential range. This will also be true for radar returns processed as described so far and so the spectra shown in Figure 4 are shown as symmetrical about the centre line (zero differential range).

However, it is also known that this technique can be applied to tracking radars and through the use of monopulse

antenna feed a one or two dimensional monopulse antenna feed in conjunction with the processing of quadrature phase r.f. signals it is found that the monopulse difference channel (hereinafter referred to as the Δ channel) naturally provides lines that are in general of different amplitudes in cells $+n_r$ and $-n_r$ respectively. The angular offsets from the monopulse antenna boresight of principle scatterers within the patch illuminated by a radar pulse can be obtained from the ratio of the line amplitudes in the monopulse difference channel and the equivalent line amplitudes in the monopulse sum-channel (hereinafter referred to as the Σ channel). Details of this process are not relevant to the inventions described herein insofar as the present embodiments are concerned with manipulating the spectra rather than improvements to the basic tracking technique.

In practice it is likely that a target will be moving with respect to the clutter with a relative velocity which has a component in the direction of the radar. Although the pure spectra remain unchanged in these circumstances, the hybrid spectrum may undergo a modification.

If, for example, a point target scatterer is moving up or down range with a relative velocity v then during a time interval T, taken to sweep the frequency f across a frequency range F, the differential range of a pair of scatterers contributing to the hybrid spectrum will change by an amount +vT or - vT, depending on the sense of the relative movement.

Over the period of the sweep the relative phases of returns from this pair will change by an amount

$$\phi = \frac{4\pi T v}{c} \left(f + \frac{F}{2}\right)$$

and since , in general, $F \ll f$

$$\phi \doteq \frac{4\pi f T v}{c} \qquad \text{Eq 2}$$

The effect of target motion in the range direction is that a target scatterer will approach some clutter scatterers within the range cell and recede from others. In these circumstances, components of lines in cells below n_n will split; those components due to up-range clutter scatterers moving in one sense along the differential range axis of the spectrum and those components due to down-range clutter scatterers moving in the opposite sense. In contrast, components of those lines in cells between n_n and n_f are caused to shift in the same sense, depending on the direction of relative target motion. A critical velocity

$v_c = \frac{cF}{fBT}$, corresponding to a phase change of $4N\pi$ can be found which leaves the spectrum in the original ($v = 0$) position, as shown in Figure 4d.

At intermediate velocities the hybrid spectrum will, in general be smeared. The variation in the shape of the hybrid spectrum is described in more detail in our copending Application (Agents Ref.P.Q.21024A) 8517564

Even if returns from clutter scatterers are weak as

compared with returns from target scatterers the hybrid spectrum may still influence significantly the shape of the composite spectrum which contains contributions from both the pure and hybrid spectra. In some applications the composite spectrum is used for the detection and identification of targets in a clutter background. The variability of the hybrid spectrum with the relative target velocity, v, may tend to hinder detection of a target. The inventor has discovered that this variability can be reduced by choosing, at random, the order in which each of the 2N frequency values is transmitted. In the example here, the returns are then reordered in accordance with a monotonic frequency sequence, prior to frequency analysis. The form of the pure spectra will be preserved; however, provided the relative velocity of the target and clutter scatterers has at least the value δv $\left(= \frac{c}{2fT}\right)$ corresponding to a phase change ϕ $(= 2\pi)$ necessary to resolve a shift in the position of a spectral line, the effect of the randomising procedure is to "whiten" the hybrid spectrum as illustrated in Figure 5 and to reduce its influence in the composite spectrum. Thus, if T = 12.8ms and f = 94 GHz, "whitening" will occur for relative velocities in excess of $\pm$ 0.125ms. It will be appreciated that since the spectra are generated on the basis of limited sampling, the individual lines contributing to the nominally flat hybrid spectrum produced by the randomising procedure will be subject to fluctuations about a constant mean. Use of a suitable selection criterion however,

possibly based on a psuedo random code may reduce such fluctuations.

Figure 6 shows one implementation of the above described procedure. The system shown includes a variable control oscillator 10 coupled to a duplexer 11 via a pulse modulation circuit 12. The oscillator receives a control voltage V_f derived from a control circuit 13 effective to select an appropriate frequency for transmission. The duplexer transmits a train of M (typically 16) pulses at the selected frequency and the control circuit then selects another frequency. Control circuit 13 includes a selection circuit 14 conditioned to choose frequencies, at random, from a progressively decremented number 2N (typically 64) of different frequency values, spanning a range F (typically 500MHz), held in a first store 15. As the frequency values are chosen they are transferred to a second store 16 and when all 2N values have been selected the contents of store 16 are returned to store 15 and the entire selection procedure is repeated.

Returns received in response to each transmitted pulse are combined in a mixing circuit 17 with a local oscillator signal thereby to generate a signal at 1F. This 1F signal is then passed to a square law detector 18 and, after range gating in a sample and hold circuit 19, fed via an analogue-to-digital conversion circuit 20 to a buffer store 21. The contents of store 21 are summed in an integrator 22 with other signals derived from earlier pulses transmitted at the same frequency,

the summation for each frequency value being distributed, in range order, to a respective frequency bin B_1; B_2 .....B_{2N} of a multichannel store 23.

The contents of the 2N frequency bins are then passed, in accordance with a monotonic frequency sequence, to a transformation circuit 24 for each range cell in turn. The transformation circuit carries out a Fast Fourier Transform on each set of 2N signals and generates respective sets of 2N transformation signals, one set for each range cell. The 2N transformation signals form the components of a spectrum in the differential range domain and are stored in respective bins D_1, D_2 ......D_{2N} of a further store 25 for further analysis. To assist in detection of a target suitable threshold levels may be set to monitor one or more selected channels.

To reduce the amount of presumming the 2N frequencies could be transmitted several times, preferably in accordance with different sequences, during the available dwell time, and this would tend to reduce fluctuations in the overall whitened spectrum. Furthermore a circuit (not shown) could also be provided to reduce the effect of the "white" part of the spectrum. This may simply involve reducing the content of each channel in the observed spectrum by the content in the channel having the smallest output, or preferably by setting a detection threshold derived by averaging levels in the upper part of the spectrum, where the pure clutter spectrum is relatively insignificant. At the same time, the standard deviation of the

"white" spectrum could be obtained and, if required, this could be weighted and added to the average to obtain the threshold.

In another application the target may not be moving with respect to the clutter but, as in the case of a airborne radar operating in a search mode, the antenna beam may be scanned in azimuth to illuminate areas to either side of the line of travel of the airborne vehicle. The effect of this, when observing scatterers to either side of the line of travel, will be to induce an apparent movement of one of the scatterers in a pair with respect to the other, as perceived at the radar.

If, for example, as is represented in Figure 7, the radar is moving on a horizontal track at a velocity V and at a particular azimuthal scan angle ψ the antenna beam, assumed to have a negligible depression angle, illuminates a pair of scatterers S_1, S_2 at a range R and having a cross-range separation d, the induced relative velocity v_i of the scatterers towards the radar will be given by the expression

$$v_i = \frac{Vd}{R} \sin \psi \qquad \text{Eq 3}$$

The corresponding spectral line will undergo a shift provided that

$$v_i \geqslant \delta v = \frac{c}{2fT} \qquad \text{Eq 4}$$

Thus, combining equations 3 and 4, an induced velocity v_i will affect lines in both the pure and hybrid spectra provided the corresponding pairs of scatterers have a cross range

separation

$$\delta \geq \breve{d} = \frac{cR}{2fTv \sin\psi} \qquad \text{Eq 5}$$

In some operation circumstances, particularly if the clutter returns are relatively weak as compared with the target returns, the frequency randomising technique, described hereinbefore, can be used to exploit the effect of induced velocity.

If the azimuthal beamwidth of the radar antenna is α returns will be received from pairs of scatterers having a cross-range separation of up to $R\alpha$. However, if $\bar{d}$ is set so as to be equal the maximum possible cross-range dimension D of a target, the pure spectrum, due to target scatterers only, will be unaffected by the randomising procedure, whereas the pure spectrum due to clutter scatterers only will be subject to some "whitening". Since the probability of possible pairings decreases as a function of differential range r, as shown in Figure 4a the effect of the randomising procedure is to reduced the power in the spectrum by a factor $\hat{\rho} = \frac{R\alpha}{2D}$ producing a corresponding improvement in the signal-to-clutter ratio.

If d is to be retained at the chosen value D the frequency period T, given by $\frac{cR}{2fDV \sin\psi}$ needs to be adjusted as the scan angle ψ changes.

Thus if R = 1km, f = 94GHz, D = 4m and V = 150 ms^{-1} then at a scan angle $\psi = \pm 15^{\circ}$ the sweep period T is 12.8ms and $\hat{\rho}$ is 8dB and at a scan angle $\psi = \pm 30^{\circ}$ the sweep period T is 6.4ms.

However, the sweep period should not exceed the dwell time of the beam and so as ψ approaches 0° the improvement $\hat{\rho}$ in signal-to-clutter ratio will approach OdB as shown in Figure 8.

If the elevation beam width ε equals the azimuth beam width α the scanning pattern shown in Figure 9a can be adopted to ensure that successively scanned swathes on the ground are contiguous. Adopting this approach, the beam elevation is advanced by an amount ε at the limit $\pm\Psi$ of each scan and is progressively decreased, by ε, during the next scan.

If the height of the radar about the ground is H the scan period for successive clockwise and anticlockwise scans will be

$$\tau = \frac{2R^{2}\varepsilon}{VH}$$

and if each swathe on the ground has a width S the maximum scan angle Ψ is given by the expression

$$\Psi = \sin^{-1}\left(\frac{S}{2R}\right)$$

It then follows that the azimuthal dwell time of the antenna beam is

$$\frac{\alpha\tau}{2\Psi}$$

and so the benefit of the randomising procedure can be exploited only for scan angles

$$\psi \geqslant \breve{\psi} = \sin^{-1}\frac{cR\Psi}{\alpha fDv}$$

Thus, a central portion of each swathe, having a width

$$2R\sin\breve{\psi} = \frac{2cR^{2}\Psi}{\alpha fDV}$$

, will yield a reduced value of $\hat{\rho}$, the proportion z of the swathe for which $\hat{\rho}$ is at a maximum

being given by the expression

$$z = 1 - \frac{2R\sin\breve{\psi}}{S} \doteq 1 - \frac{cR}{\alpha fDV}$$

Thus if $R = 800\text{m}$, $\alpha = 50\text{mrad}$, $f = 94\text{GHz}$, $D = 4\text{m}$ and $V = 150\text{ms}^{-1}$ then $z = 91\%$ and the central portion of the swathe which does not yield the maximum improvement will be about 54m wide.

An alternative scanning pattern, shown in Figure 9b, can be adopted to ensure that the antenna beam illuminates the same points on the ground during two successive scans. To this end, the elevation angle is increased by ε at one end of the scan and is alternatively increased or decreased, by ε, at the other end. In this case the proportion z' of each swathe for which $\hat{\rho}$ is not at a maximum is given by the expression

$$z' = 1 - \frac{2cR}{fDV}$$

, and taking the same example as before has a value 82%

If the signal-to-noise ratio permits, it would be possible to achieve some increase in value of z by modulating the azimuthal scan velocity thereby to slow down the scan rate in the central portion of the scan.

Finally it will be understood that the techniques described herein are not restricted to radars operating with a fixed or single antenna polarisation. Several spectra may be generated simultaneously or sequentially using co-polar and cross-polar responses from scatterers and the techniques described herein may be used to exploit the effects of scatterer motion in any or all of these spectra.

MWB/BJN

CLAIMS

1. A radar comprising,

means for transmitting radar pulses at different frequencies and for receiving corresponding returns,

transformation means to derive from said returns a plurality of transformation signals representing a distribution of pairs of radar scatterers, which comprise target and or clutter, as a function of their differential range,

wherein said transmission means is arranged to transmit radar pulses at successive frequencies selected, at random, from a progressively decremented number of available frequencies and means are provided to order said returns in accordance with a monotonic sequence of said transmitted frequencies before they are passed to said transformation means thereby to emphasise the effect of a target in said plurality of transformation signals as compared with the effect of clutter, and comparison means are provided to compare the power in a selected one or a selected group of differential range cells with a threshold value, thereby to detect a target.

2. A radar according to Claim 1 wherein said transmission means is arranged to transmit a number of radar pulses at each said frequency.

3. A radar according to Claim 1 or Claim 2 suitable for use with an airborne carrier moving on a flight path, wherein said transmitting and receiving means generate a response characteristic which, in use, is scanned, in azimuth, relative to a scene, and means are provided to control the period for transmitting said selected frequencies in dependence on the

instantaneous azimuthal position of said characteristic, thereby to further emphasise the effect of a target in said plurality of transformation signals as compared with the effect of clutter.

4. A radar according to Claim 3 wherein said period is related inversely to sin ψ, where ψ is the angle subtended by said response characteristic and said flight path.

5. A radar substantially as hereinbefore described by reference to the accompanying drawings.

EXAMINER'S REPORT TO THE COMPTROLLER
UNDER SECTION 17(5)
(The Search Report)

8517565

FIELD OF SEARCH: The search has been conducted through the relevant published UK patent specifications and applications, a applications published under the European Patent Convention and the Patent Co-operation Treaty (and such other documents as n be mentioned below) in the following subject-matter areas:-

UK Classification H4D (DRPT, DRPU, DRPD, DRPF)

(Collections other than UK, EP & PCT:) Selected US specifications in IPC Subclass G01S

DOCUMENTS IDENTIFIED BY THE EXAMINER (NB In accordance with Section 17(5), the list of documents below may inclu only those considered by the examiner to be the most relevant of those lying within the field (and extent) of search)

Category	Identity of document and relevant passages	Relevant to claim(s
-	None	-

CATEGORY OF CITED DOCUMENTS

X relevant if taken alone

Y relevant if combined with another cited document

P document published on or after the declared priority date but before the filing date of the present application

E patent document published on or after, but with priority date earlier than, the filing date of the present application

Search examiner

H E GRIFFITHS

Date of search

6 June 1986

SF